XIX MEXICAN WORKSHOP ON PARTICLES AND FIELDS, UNIVERSIDAD DE GUANAJUATO CAMPUS LEÓN
21-OCT-2025

New Physics in Flavor anomalies

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New Physics in Flavor anomalies

- New Physics?
- Flavor anomalies
- New physics in $B \to K\nu\nu$

Standard Model and Beyond

Neutrino mass models
Oscillation anomalies

Astrophysical observations
Cosmology

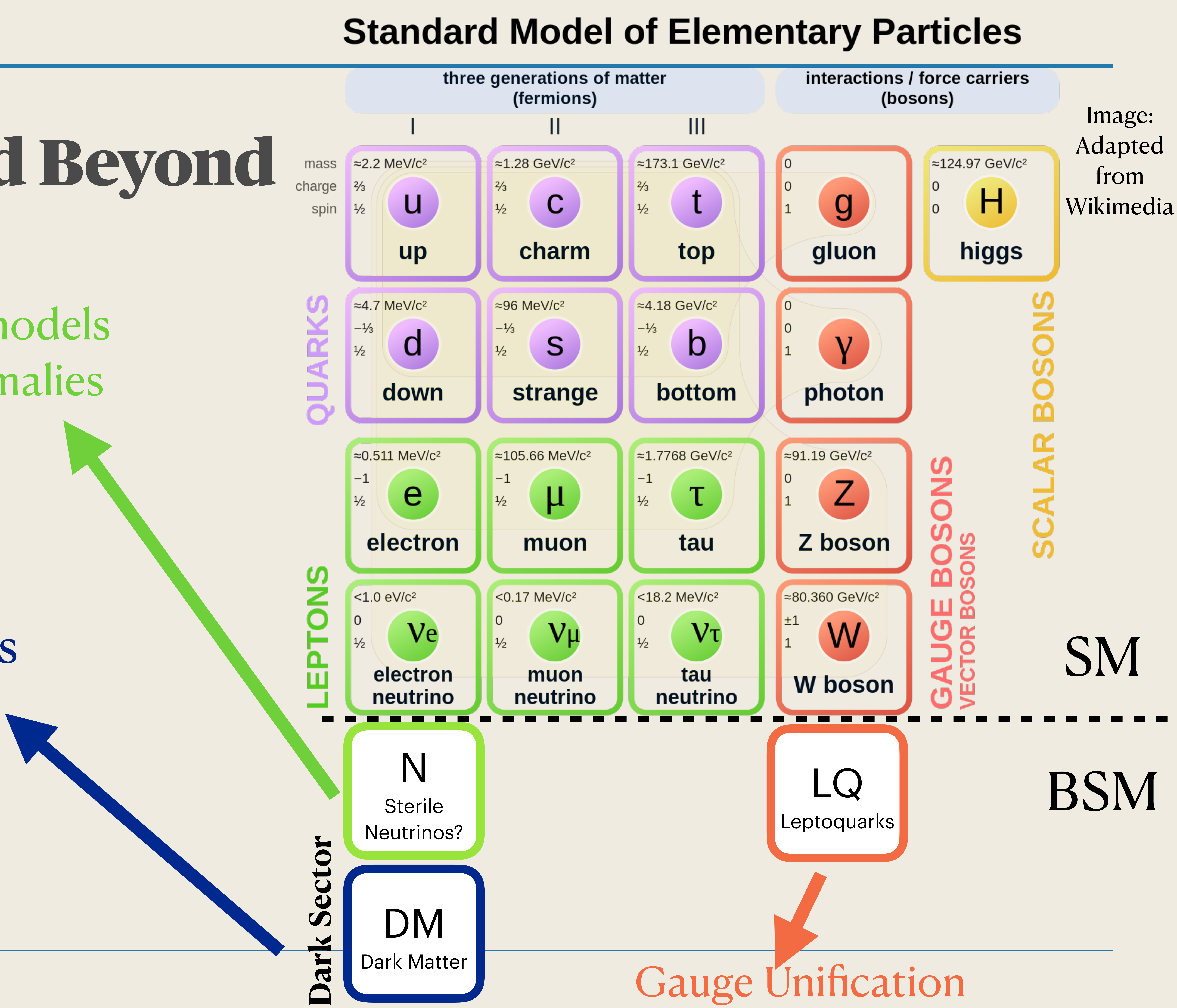


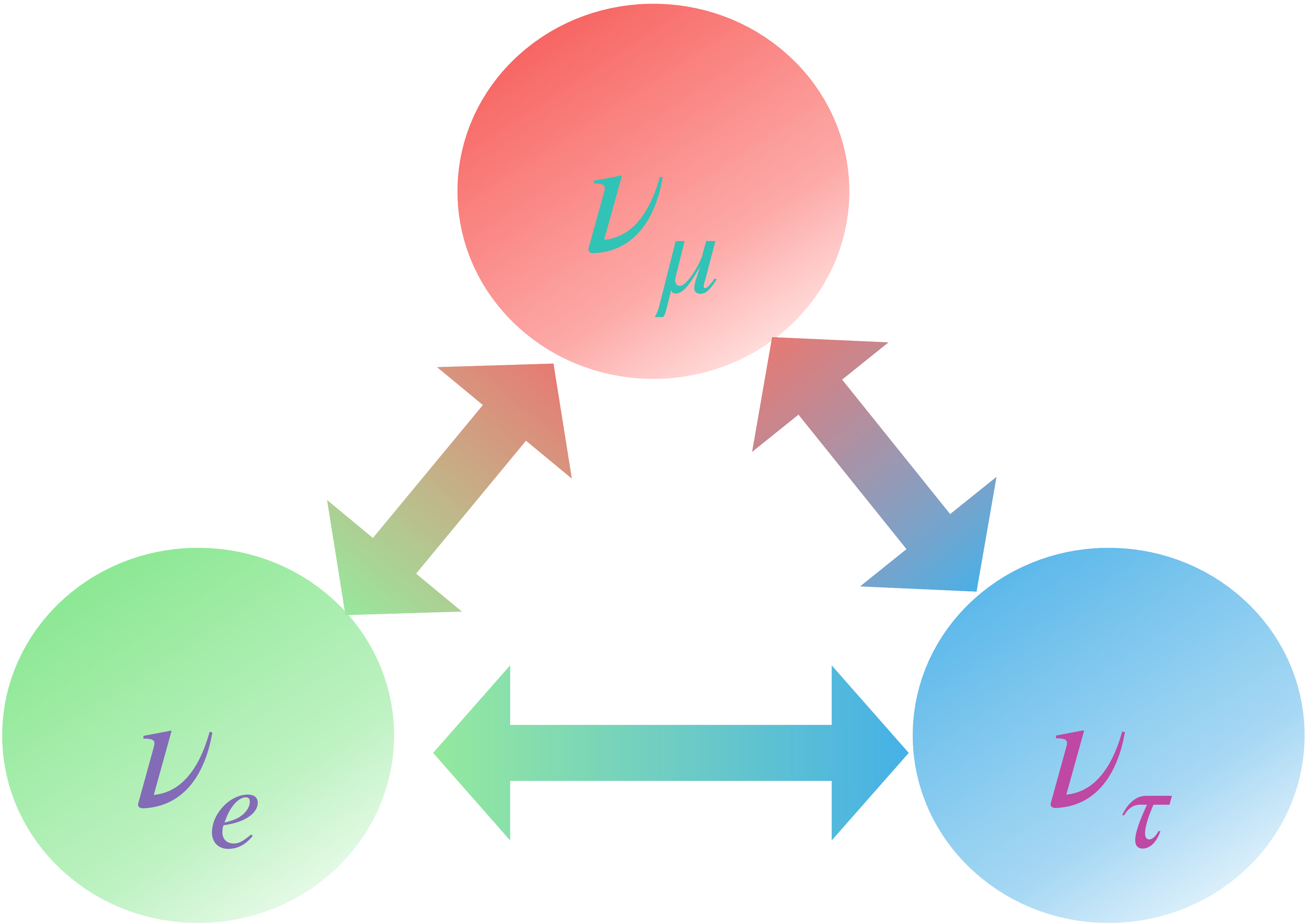
Image: Adapted from Wikimedia

Massive Neutrinos

- Neutrino Oscillations
  - Super-Kamiokande + SNO
- Neutrino masses + mixing in leptonic sector

$$|\nu_e >= U_{e1}|\nu_1 > +U_{e2}|\nu_2 > +U_{e3}|\nu_3 >$$

$$P_{\alpha\to\beta} = \left| \langle \nu_\beta \mid \nu_\alpha(L) \rangle \right|^2 = \left| \sum_j U^*_{\alpha j} U_{\beta j} e^{-i\frac{m_j^2 L}{2E}} \right|^2$$



NuFIT 6.0 (2024)

$$|U|_{3\sigma}^{\text{IC19 w/o SK-atm}} = \begin{pmatrix} 0.801 \to 0.842 & 0.519 \to 0.580 & 0.142 \to 0.155 \\ 0.248 \to 0.505 & 0.473 \to 0.682 & 0.649 \to 0.764 \\ 0.270 \to 0.521 & 0.483 \to 0.690 & 0.628 \to 0.746 \end{pmatrix}$$

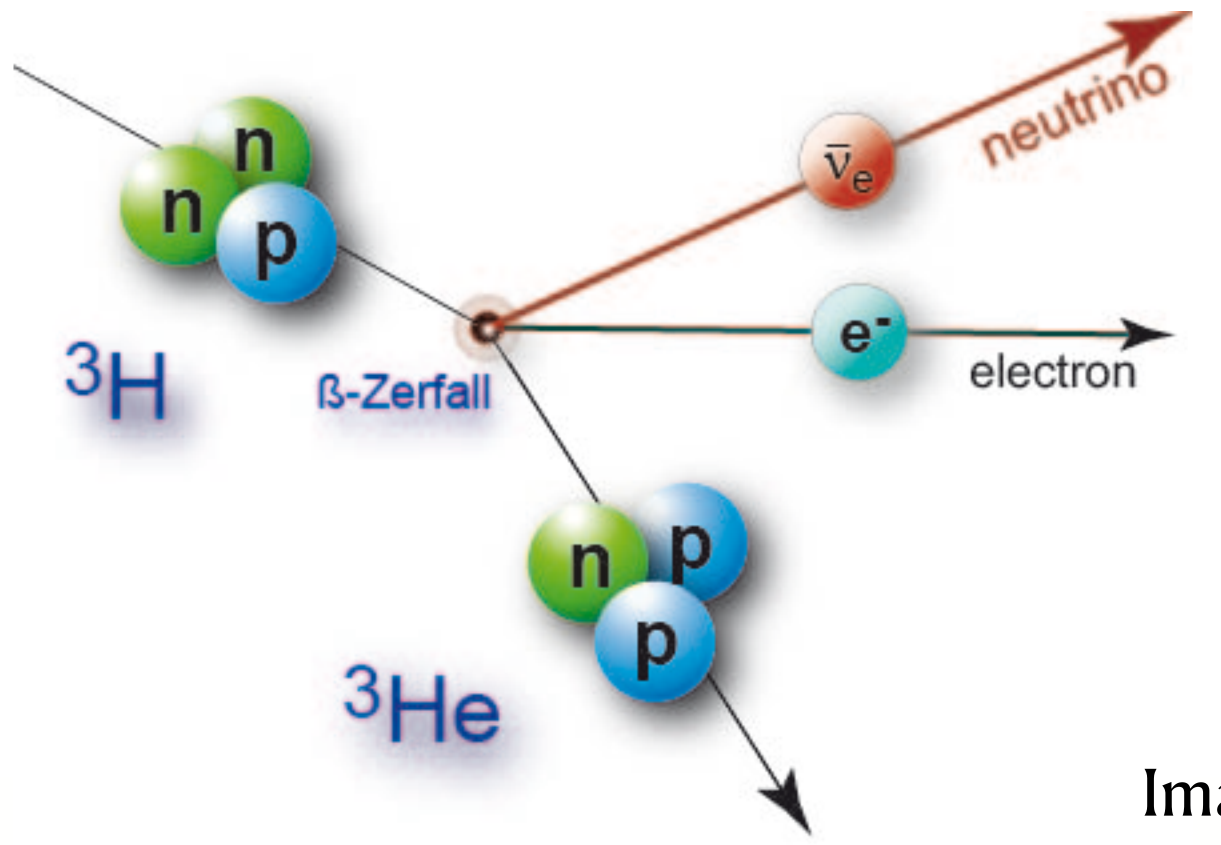
$$|U|_{3\sigma}^{\text{IC24 with SK-atm}} = \begin{pmatrix} 0.801 \to 0.842 & 0.519 \to 0.580 & 0.142 \to 0.155 \\ 0.252 \to 0.501 & 0.496 \to 0.680 & 0.652 \to 0.756 \\ 0.276 \to 0.518 & 0.485 \to 0.673 & 0.637 \to 0.743 \end{pmatrix}$$

NuFIT 6.0 (2024), www.nu-fit.org.

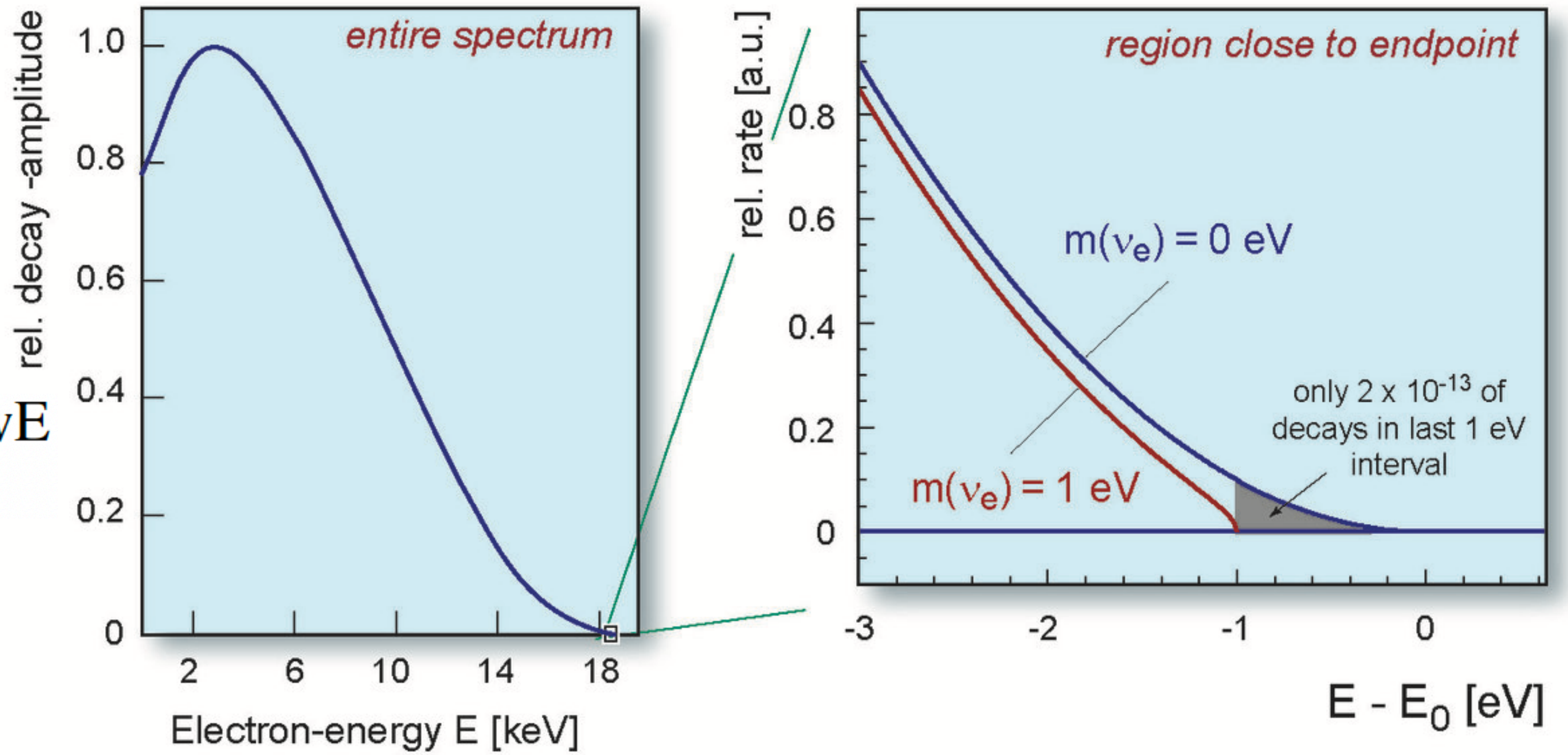
Neutrino mass scale

- Beta decay kinematics:
- $^3\text{H} \rightarrow ^3\text{He} + e^- + \bar{\nu}_e$
- KATRIN:
  - $m_\nu^{eff} < 0.8$ eV (90%) C.L.
- Cosmology

$\sum m_\nu < 0.13$ eV (95 %, *Planck* TT,TE,EE+lowE +BAO),



Images: KATRIN collaboration



Majorana and Dirac neutrinos

- Majorana mass terms
  - $M_M \bar{\nu}_L^C \nu_L$
- Lepton number non-conserving:
  - LNV in 2 units
    - Neutrinoless double beta decay

$$\langle m_{\beta\beta} \rangle = \left| U_{ei}^2 \, m_i \right|$$

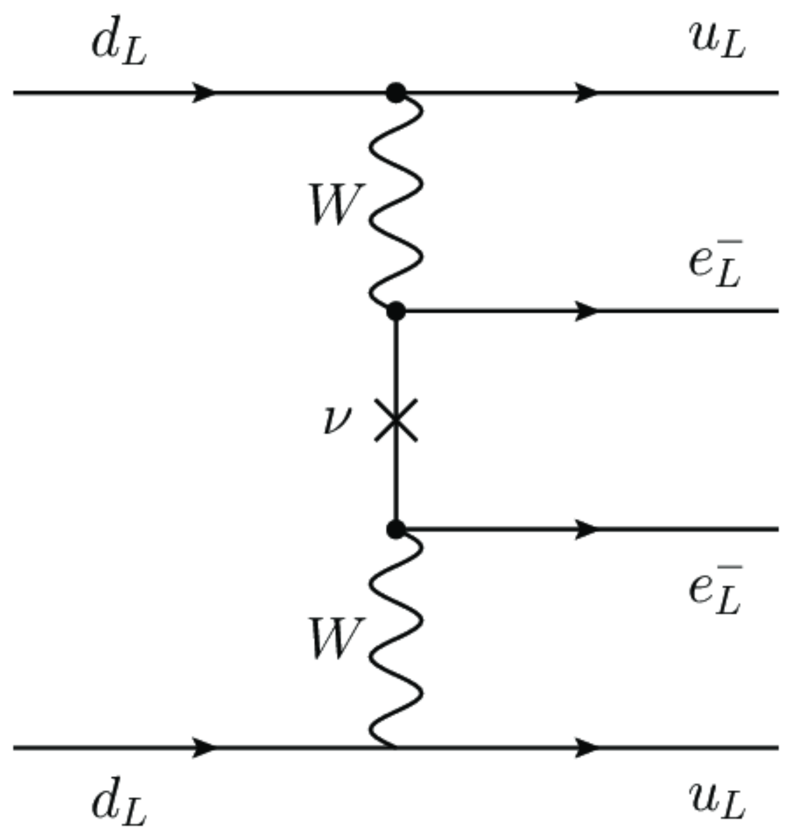
$$T_{1/2}^{0\nu} = \left(G \, |\mathcal{M}|^2 \, \langle m_{\beta\beta} \rangle^2 \right)^{-1} \simeq 10^{27-28} \left(\frac{0.01\,\mathrm{eV}}{\langle m_{\beta\beta} \rangle} \right)^2 \mathrm{y}$$

$$\langle m_{\beta\beta} \rangle < 0.061 - 0.165 \text{ eV}$$

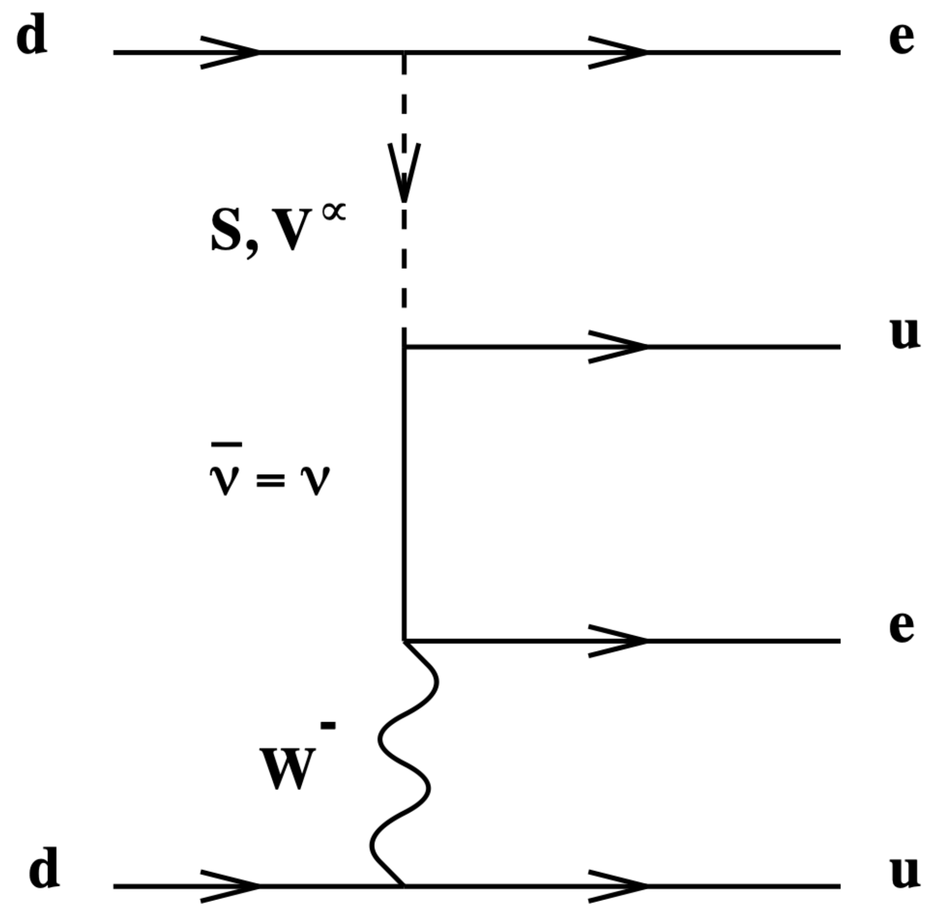
KamLAND-ZEN

$$(A, Z) \to (A, Z+2) + 2\,e^- + Q_{\beta\beta}$$

See Jorge Torres' talk in 1 hour



+ more N.P. ?



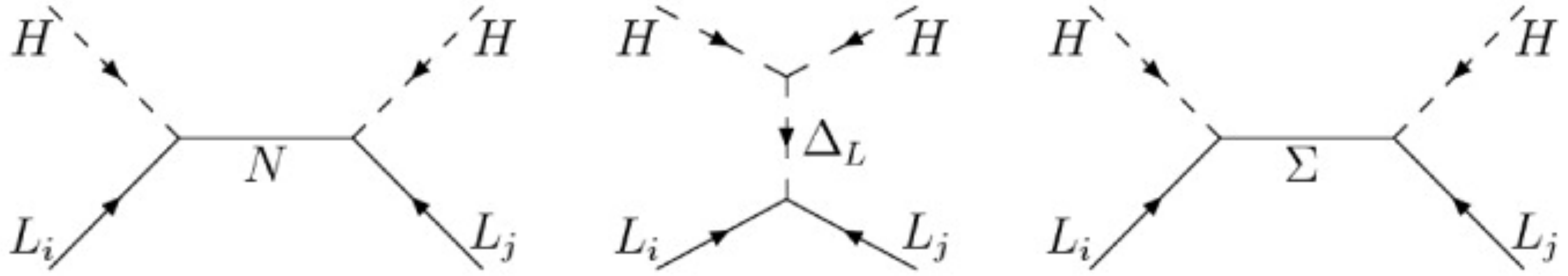
+ ... ?

M. Hirsch, H.V. Klapdor-Kleingrothaus and S.G. Kovalenko, 1996

Neutrino mass models

Majorana masses

- Weinberg operator: $\frac{C_W}{\Lambda}\bar{L}^C\tilde{H}\tilde{H}L$
- Three tree level completions:



- Loop-level completions:
  - Zee, Scotogenic, …
- LFV, Leptogenesis, Heavy Neutral Leptons, DM

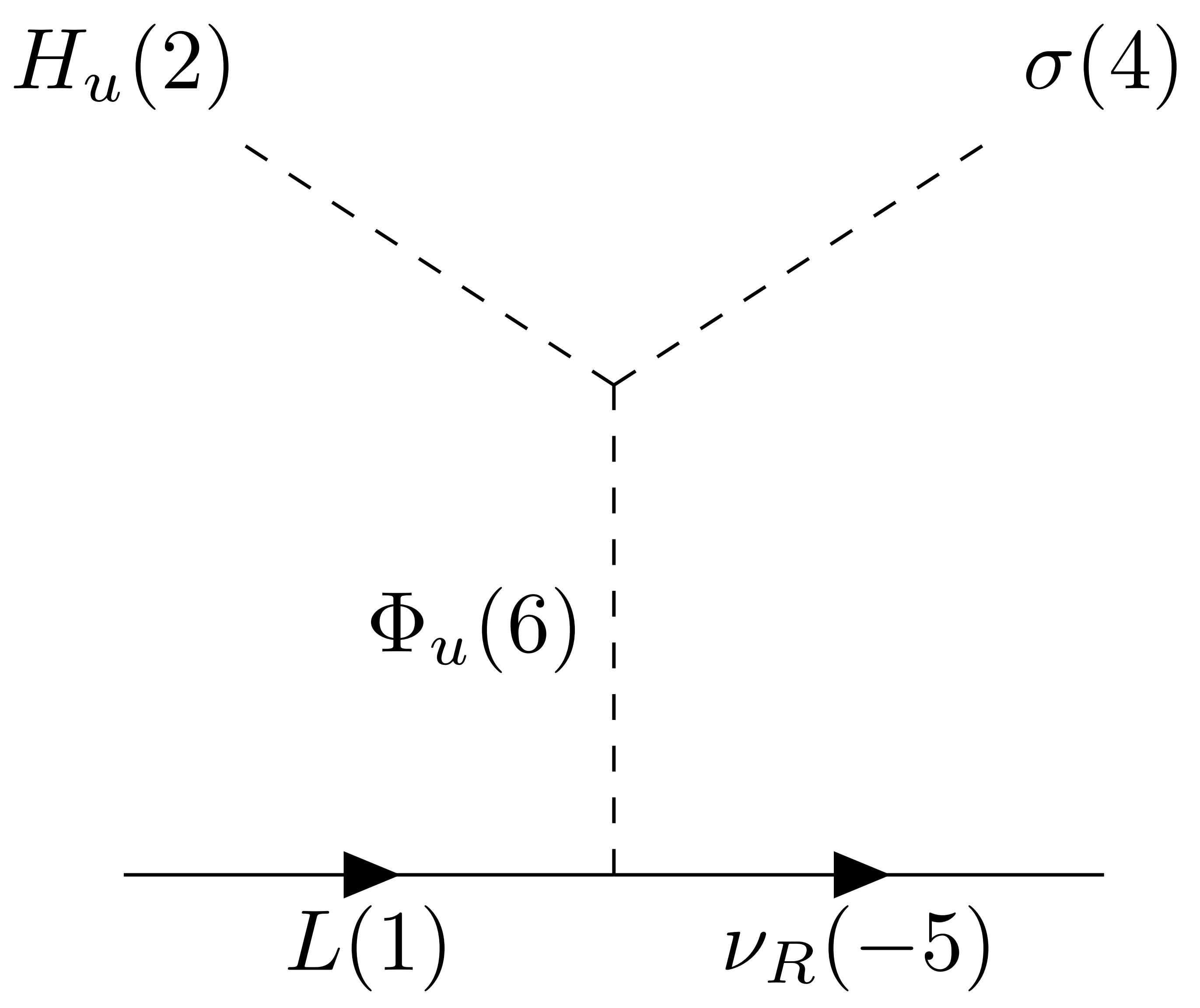
$$m_\nu \sim \frac{v^2}{M_N} = \frac{(246\ \mathrm{GeV})^2}{M_N} < 1\ \mathrm{eV}$$

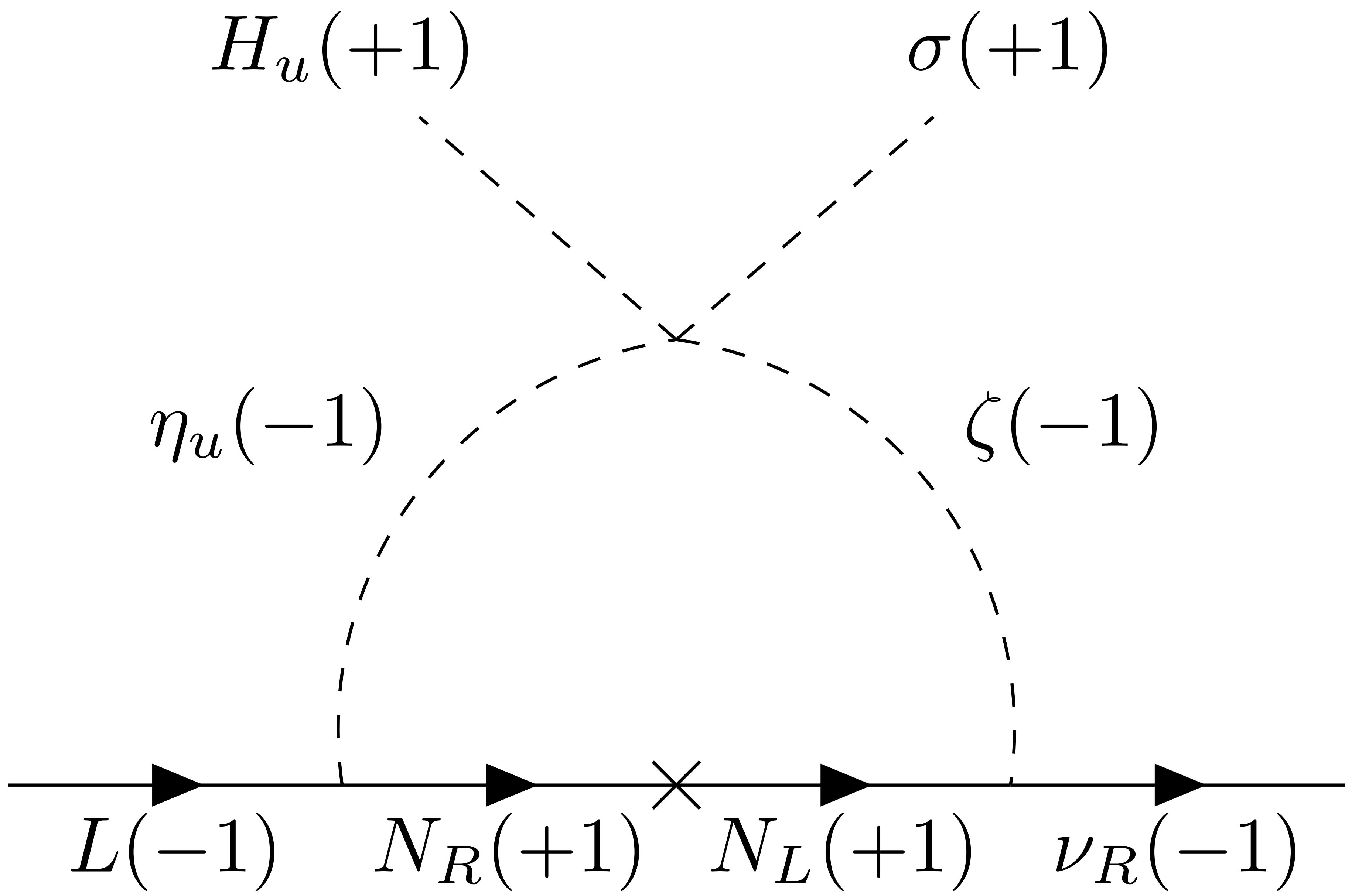
$$M_N > \sim 10^{13}\ \mathrm{GeV}$$

Neutrino mass models

Dirac masses

- Effective operator : $\dfrac{C_D}{\Lambda^N}\bar{L}\tilde{H}\nu_R(\phi)^N$
- Dirac Seesaws, loop level masses
- Remnant symmetries- Lepton number





Majorana and Dirac neutrinos

- Dirac mass terms (Charge conserving)
  - $M_D \bar{\nu}_R \nu_L$
- Needs additional right handed field $\nu_R \sim (1,1,0)$
- 4 d.o.f
- Majorana mass terms forbidden by a low energy symmetry :
  - global - gravity? , gauge - boson?
  - Why is the Yukawa coupling $Y_\nu \bar{L}\tilde{H}\nu_R$ so small? $\dfrac{m_\nu}{v_{EW}} \sim 10^{-11}$
  - Is $Y_\nu \bar{L}\tilde{H}\nu_R$ an effective coupling?

Where to look for new physics?

It depends on what you're looking for...

Flavor in the Standard Model

The flavor structure of the SM is well understood (although its origin is completely unknown):

Textbook equations: Langacker , The SM and beyond, CRC press 2017

$$\mathcal{L}_f + \mathcal{L}_{Yuk} = \mathcal{L}_\psi - \frac{g}{2\sqrt{2}}\left(J_W^\mu W_\mu^- + J_W^{\mu\dagger} W_\mu^+\right) - \frac{gg'}{\sqrt{g^2+g'^2}} J_Q^\mu A_\mu - \frac{\sqrt{g^2+g'^2}}{2} J_Z^\mu Z_\mu \equiv \mathcal{L}_\psi + \mathcal{L}_W + \mathcal{L}_Q + \mathcal{L}_Z,$$

Rewriting the currents in terms of mass eigenstates

$$J_W^{\mu\dagger} = 2\bar{\nu}_L \gamma^\mu \underbrace{A_L^{\nu\dagger} A_L^e}_{V_\ell} e_L + 2\bar{u}_L \gamma^\mu \underbrace{A_L^{u\dagger} A_L^d}_{V_q} d_L, \qquad J_W^\mu = 2\bar{e}_L \gamma^\mu V_\ell^\dagger \nu_L + 2\bar{d}_L \gamma^\mu V_q^\dagger u_L,$$

Weak charged current has nondiagonal flavor couplings in the mass eigenstate basis: The CKM and PMNS matrices are the sole source of flavor violation in the SM

Flavor in the Standard Model

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \quad |V_{\rm CKM}| = \begin{pmatrix} 0.97435 \pm 0.00016 & 0.22500 \pm 0.00067 & 0.00369 \pm 0.00011 \\ 0.22486 \pm 0.00067 & 0.97349 \pm 0.00016 & 0.04182^{+0.00085}_{-0.00074} \\ 0.00857^{+0.00020}_{-0.00018} & 0.04110^{+0.00083}_{-0.00072} & 0.999118^{+0.000031}_{-0.000036} \end{pmatrix},$$

Particle Data Group 2025

Measure these in clean observables with large cross sections, low theoretical uncertainties.

With these measured and under control, we have “understood” flavor structure in the SM : CKM for quark flavor transitions and lepton flavor universality.

Z couplings are diagonal and only one Higgs in the SM precludes tree-level FCNC

If the SM is enlarged to explain neutrino masses : a richer flavor pheno (at the very least in the lepton sector) is expected. Can it affect quarks too?

Flavor in the Standard Model

- Case in point: $B^+ \to K^+\nu\nu$ ($b \to s\nu\nu$ transition)

$$\mathcal{L}^{(6)}_{\nu\mathrm{SMEFT}} \supset \frac{1}{\Lambda^2}\sum_i \mathcal{C}_i \mathcal{O}_i \,,$$

$$\left[\mathcal{O}^{(1)}_{lq}\right]_{\alpha\beta kl} = (\bar{L}_\alpha \gamma^\mu L_\beta)\left(\bar{Q}_k \gamma_\mu Q_l\right),$$

$$\left[\mathcal{O}^{(3)}_{lq}\right]_{\alpha\beta kl} = \left(\bar{L}_\alpha \gamma^\mu \tau^I L_\beta\right)\left(\bar{Q}_k \tau^I \gamma_\mu Q_l\right),$$

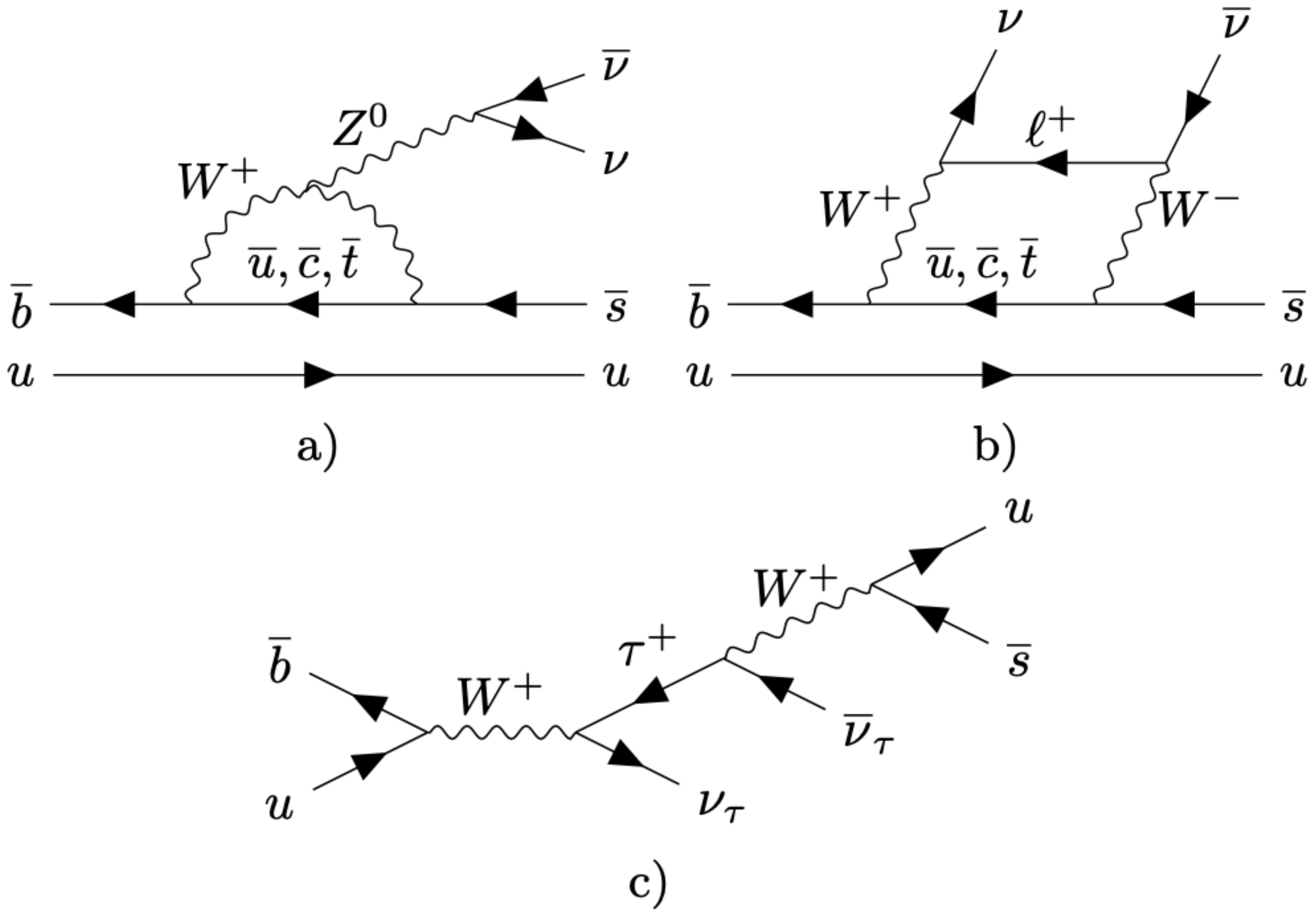
$$[\mathcal{O}_{ld}]_{\alpha\beta kl} = (\bar{L}_\alpha \gamma_\mu L_\beta)\left(\bar{d}_{kR}\gamma^\mu d_{lR}\right),$$

- SMEFT Wilson Coefficients calculable from SM input, one loop contributions

New Physics?

Meson decay anomalies

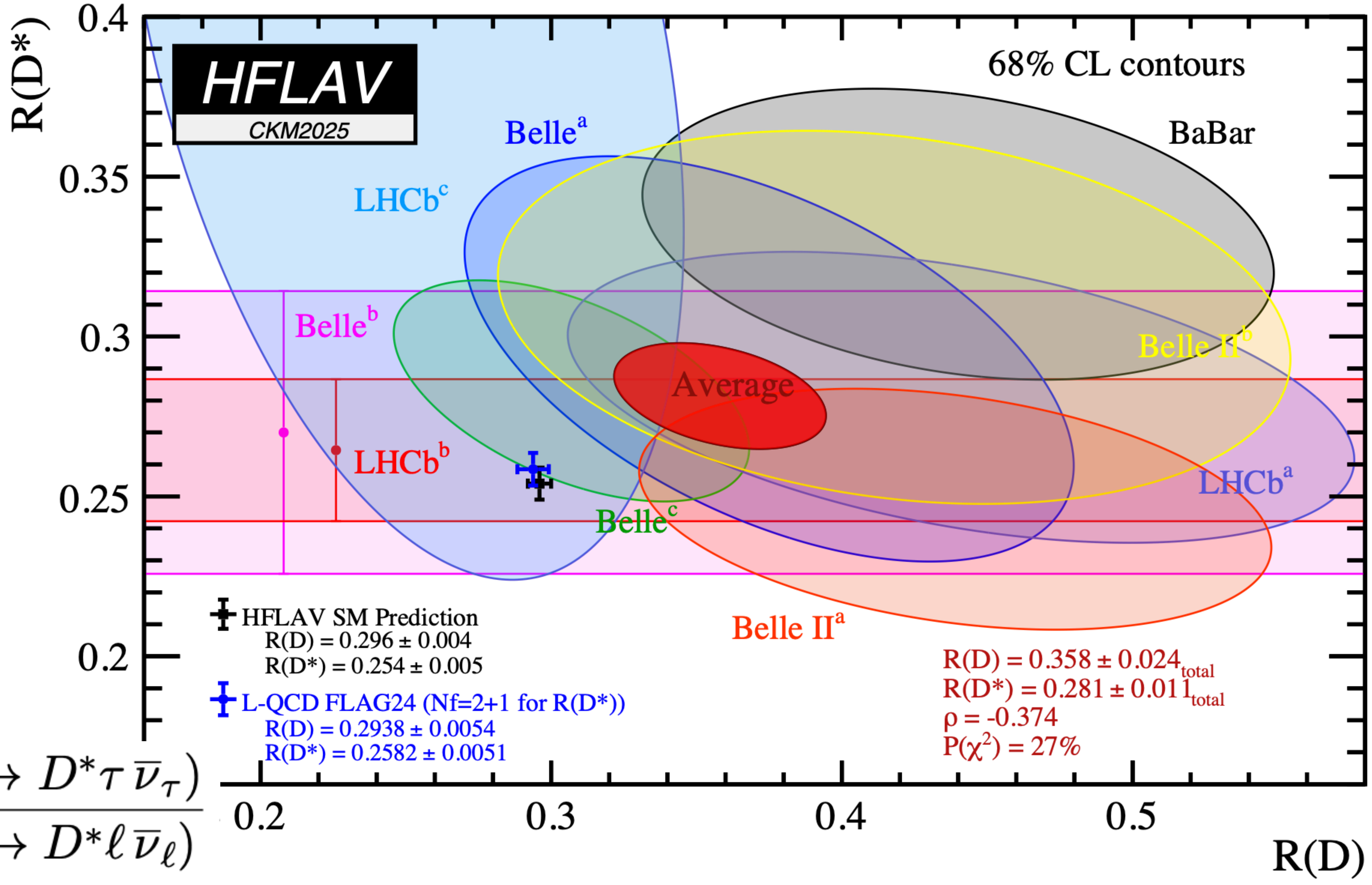
- $B^+ \to K^+\nu\nu$
- SM BR:
- $\mathscr{B}(B^+ \to K^+\nu\nu)_{SM} = (5.58 \pm 0.37) \times 10^{-6}$
- Belle- II 2023 result:
- $\mathscr{B}(B^+ \to K^+\nu\nu)_{exp} = (2.3 \pm 0.7) \times 10^{-5}$
- 2.7σ tension - excess



New Physics?

Meson decay anomalies

- $R_{D^{(*)}}: b \rightarrow cl\nu$
- Test of Lepton Flavor Universality - Weak processes are driven by lepton flavour blind couplings - Different decay widths, cs should only depend on kinematics



$$R_D \equiv \frac{\mathcal{B}(\overline{B} \to D\,\tau\,\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D\,\ell\,\overline{\nu}_\ell)}, \qquad R_{D^*} \equiv \frac{\mathcal{B}(\overline{B} \to D^*\tau\,\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^*\ell\,\overline{\nu}_\ell)}$$

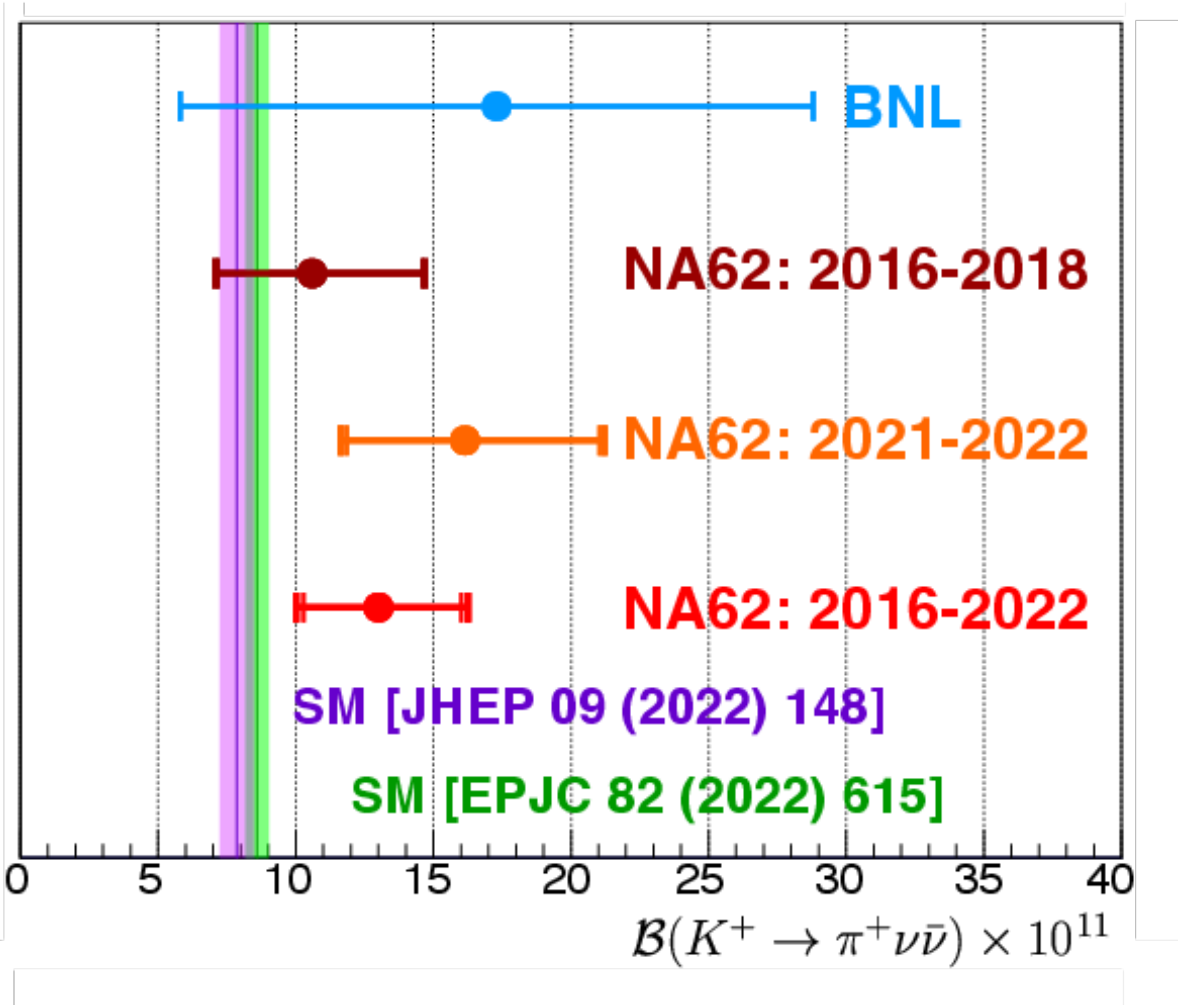
HFLAV group CKM 2025 average

New Physics?

Meson decay anomalies

- $K^+ \to \pi^+ \nu\nu : b \to cl\nu$
- Recent result from NA62 :
- Central experimental value above SM expectation (although the uncertainty is relatively large at the moment).

Jürgen's talk on Friday



NA62 collaboration, 2025

New Physics?

- $R_{K^{(*)}}$: Longstanding excess in expected $B \to K\mu\mu$ branching ratio wrt $B \to K\ell\ell$ @ LHCb. Appeared to be coming from new muon physics - maybe connected to muon g-2?
- LHCb results in 2023 show experimental $R_{K^{(*)}}$ in agreement with SM.

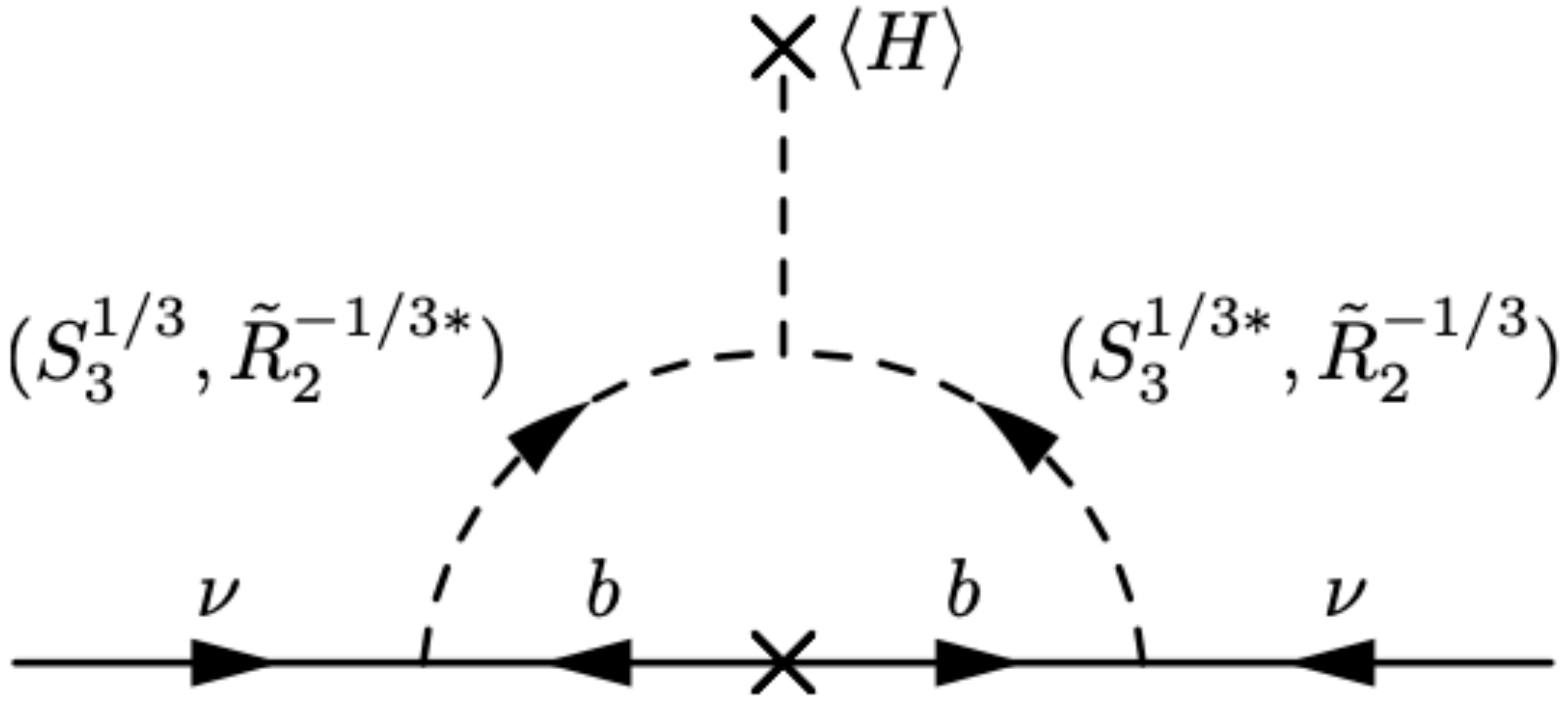
- $b \to s\ell\ell$ now appears to respect flavor universality
- muon g-2 anomaly is dead too

Can we look for new physics from the neutrino sector in these observables?

Yes, quark new physics + neutrino new physics = leptoquarks (among others)

Neutrino masses + new physics w. LQs

- Majorana Masses with LQs:
- LQs have definite lepton number
- Majorana masses require L breaking:
  - At least 2 leptoquarks with different L must be introduced and L broken with LQ mixing



$$S_3 = (\overline{\mathbf{3}}, \mathbf{3}, 1/3)$$

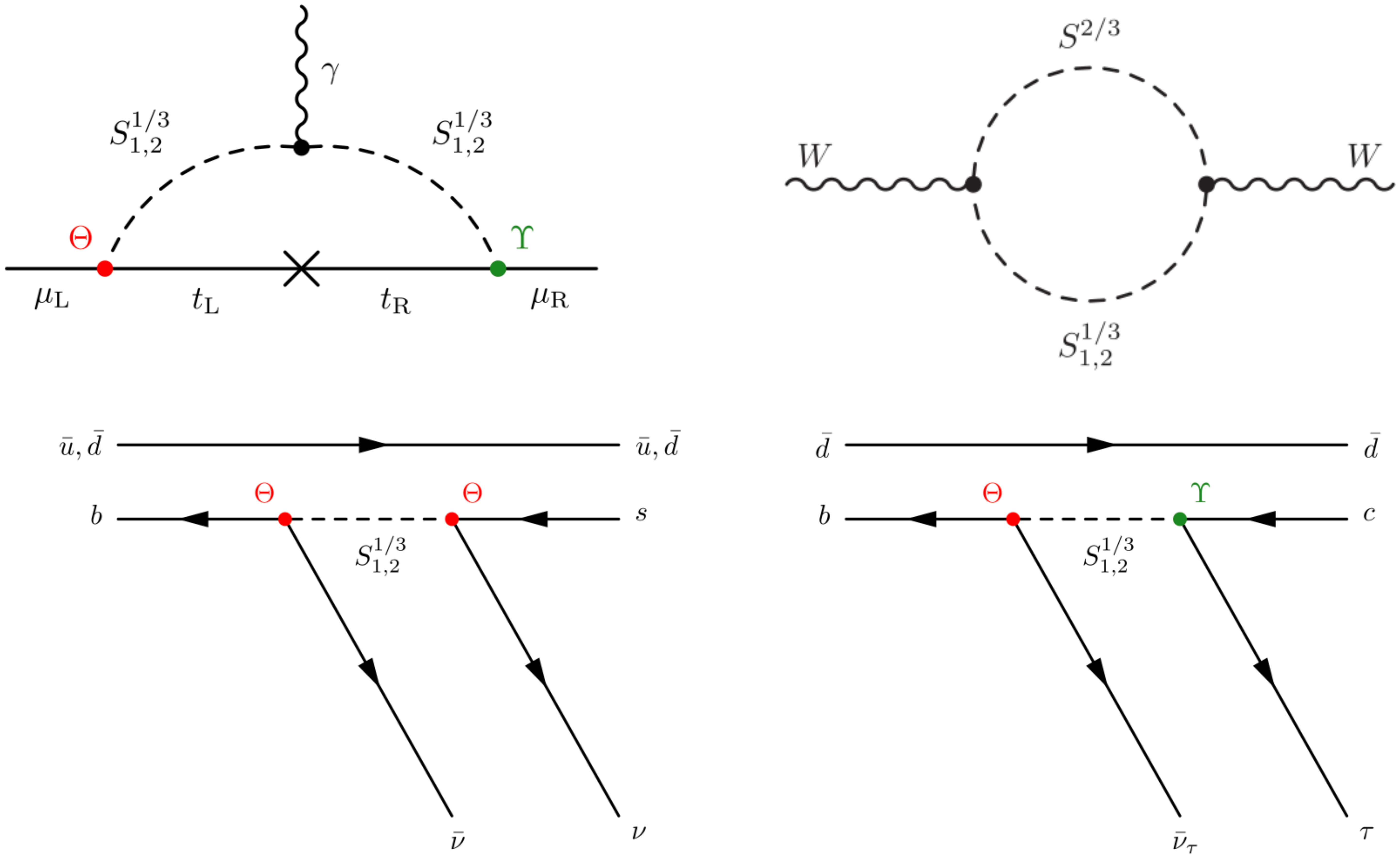
$$\tilde{R}_2 = (\mathbf{3}, \mathbf{2}, 1/6)$$

From I. Doršner et. al., Physics of leptoquarks in precision experiments and at particle colliders

Neutrino masses + new physics w. LQs

S3+R2 model

- muon g-2
- R_D
- CDF M_W
- $B \to K\nu\nu$



Freitas et. al. Interplay between flavor anomalies and neutrino properties, 2023

Dirac neutrinos and Leptoquarks

- For Dirac ν no L breaking is necessary: only one type of LQ is needed (+ the right handed ν).
- To forbid dim-4 neutrino mass a symmetry must be introduced and kept at low energies
- Consider $S \sim (3,1,-2/3)$

	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$	Z_3
L	1	2	$-1/2$	x	ω
ℓ_R	1	1	-1	x	ω
Q_L	1	2	$1/6$	$2x$	ω^2
u_R	1	1	$2/3$	$2x$	ω^2
d_R	1	1	$-1/3$	$2x$	ω^2
ν_R	1	1	1	$4x$	ω
H	1	2	$1/2$	0	1
S	3	1	$-2/3$	$3x$	1
S'	3	1	$-2/3$	$6x$	1

JHEP
PUBLISHED FOR SISSA BY SPRINGER
RECEIVED: *April 8, 2025*
REVISED: *July 4, 2025*
ACCEPTED: *August 3, 2025*
PUBLISHED: *September 5, 2025*

Leptoquark-mediated Dirac neutrino mass and its impact on $B \to K\nu\bar{\nu}$ and $K \to \pi\nu\bar{\nu}$ decays

Chuan-Hung Chen,[a,b] Cheng-Wei Chiang[c,b] and Leon M.G. de la Vega[b]

Dirac neutrinos and Leptoquarks

$$-\mathcal{L}_Y = \bar{L}Y^{\ell}H\ell_R + \bar{Q}Y^{u}\tilde{H}u_R + \bar{Q}Y^{d}Hd_R + \overline{Q^C}\,Y^{LL}\,i\tau_2\,L\,S^* + \overline{u_R^C}\,Y^{RR}\,\ell_R S^* + \overline{d_R^C}\,\overline{Y}^{RR}\,\nu_R S'^* + \text{H.c.}\,,$$

After LQ mixing and charged fermion diagonalization we have the following physical Yukawa couplings

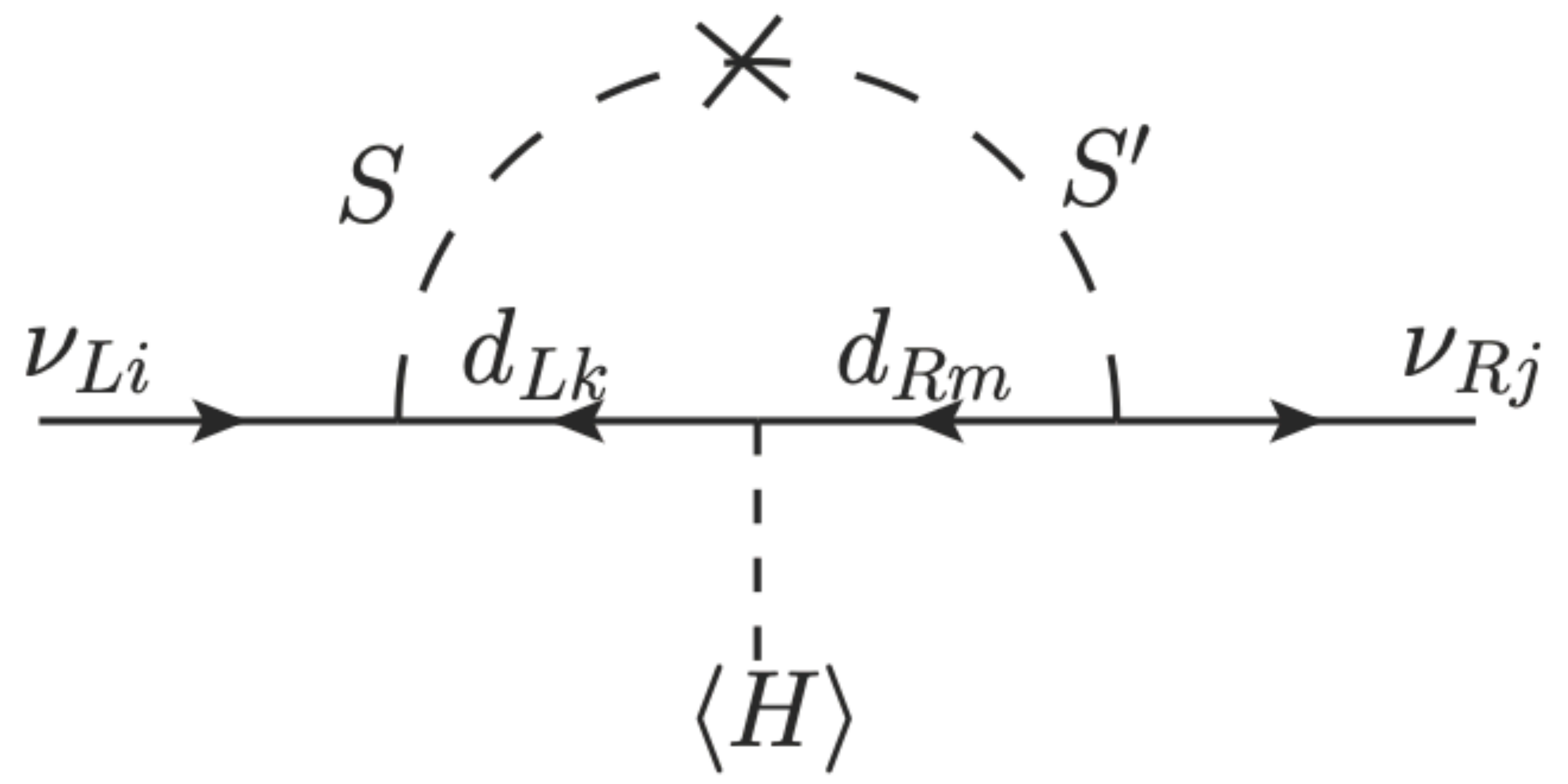
$$\mathcal{L}_Y \supset (\overline{u_L'^C}\xi_1 e_L' + \overline{d_L'^C}\xi_2\nu_L + \overline{u_R}^C\xi_4 e_R)(\cos\theta_S S_A - \sin\theta_S S_B) + (\overline{d_R}^C\xi_3\nu_R)(\sin\theta_S S_A + \cos\theta_S S_B) + h.c.$$

$$\xi_1 = V_L^{u^T}Y^{LL}V_L^{\ell}\,,\quad \xi_2 = -V_L^{d^T}Y^{LL}\,,\quad \xi_3 = V_R^{d^T}\overline{Y}^{RR}\,,\quad \xi_4 = V_R^{u^T}Y^{RR}V_R^{\ell}\,.$$

Dirac neutrino masses are induced at one loop:

$$M_\nu = f(M_A, M_B, \theta_S)\xi_2^\dagger m_d \xi_3,$$

$$f(M_A, M_B, \theta_S) = \frac{\cos\theta_S \sin\theta_S}{(4\pi)^2}\ln\left(\frac{M_A^2}{M_B^2}\right)$$



BSM phenomenology

down quark transitions with neutrinos (L and R):

$$\mathcal{L}_{d\to d'\nu\bar{\nu}} = \frac{1}{2m_{S_A}^2}(\tilde{\xi}_2)_{ij}(\tilde{\xi}_2)^\dagger_{k\ell}\,\overline{d_{L\ell}}\gamma_\mu d_{Li}\,\overline{\nu_{Lk}}\gamma^\mu\nu_{Lj} + \frac{1}{2m_{S_B}^2}(\tilde{\xi}_3)_{ij}(\tilde{\xi}_3)^\dagger_{k\ell}\,\overline{d_{R\ell}}\gamma_\mu d_{Ri}\,\overline{\nu_{Rk}}\gamma^\mu\nu_{Rj}\,.$$

This BSM effects can enhance $B \to K\nu\nu$, $K^+ \to \pi^+\nu\nu$ and $K_L \to \pi^0\nu\nu$

Lepton Flavor Violation

- Loop diagrams with LQs can induce $\ell_i \to \ell_j \gamma, \ell_i \to 3\ell_j$
- <u>**Tree**</u>-level exchange of a LQ can induce muon to electron conversion in a nucleus

- Rule of thumb is to check $\ell_i \to \ell_j \gamma, \ell_i \to 3\ell_j$ enhancements in neutrino mass models before muon to electron conversion. With LQs it can be the other way around!

More to be discussed on LFV with LQs in the afternoon by Juan Pablo Hoyos!

B and K meson oscillations and $b \to u_j \ell \nu_i$

- Integrating out the LQs also induces :

$$\mathcal{H}^{NP}_{\Delta F=2} = \frac{1}{128\pi^2 m^2_{S_A}} \left[\bar{d}_j \gamma_\mu (\tilde{\xi}_2 \tilde{\xi}_2^\dagger)^*_{ji} P_L d_i\right] \left[\bar{d}_j \gamma^\mu (\tilde{\xi}_2 \tilde{\xi}_2^\dagger)^*_{ji} P_L d_i\right] + \frac{1}{128\pi^2 m^2_{S_B}} \left[\bar{d}_j \gamma_\mu (\tilde{\xi}_3 \tilde{\xi}_3^\dagger)^*_{ji} P_R d_i\right] \left[\bar{d}_j \gamma^\mu (\tilde{\xi}_3 \tilde{\xi}_3^\dagger)^*_{ji} P_R d_i\right] ,$$

Meson-antimeson oscillations

$$\mathcal{H}_{b \to u_j \ell \bar{\nu}} = \frac{1}{2m^2_{S_A}} \left[-(\tilde{\xi}_2^T)_{\ell' 3} (\xi_1^*)_{j\ell} \, \bar{u}_{Lj} \gamma^\mu b_L \, \bar{\ell}_L \gamma_\mu \nu_{\ell' L} + (\tilde{\xi}_2^T)_{\ell' 3} (\xi_4^*)_{j\ell} \, \bar{u}_{Rj} b_L \, \bar{\ell}_R \nu_{\ell' L} - \frac{1}{4} (\tilde{\xi}_2^T)_{\ell' 3} (\xi_4^*)_{j\ell} \, \bar{u}_{Rj} \sigma_{\mu\nu} b_L \, \bar{\ell}_R \sigma^{\mu\nu} \nu_{\ell' L} \right] .$$

R_D

Numerical results

- Input: Neutrino oscillation parameters in a Casas-Ibarra like parametrization

$$\mathbf{m}_\nu^{\text{Dirac}} = V_L^\nu \mathbf{m}_\nu^{\text{dia}} V_R^{\nu\dagger} = \xi_2^\dagger \widetilde{\mathbf{m}}_d \xi_3 \,,$$

$$\xi_2 = \frac{1}{\sqrt{\widetilde{\mathbf{m}}_d}} \eta^\dagger U \epsilon^\dagger \sqrt{\mathbf{m}_\nu^{\text{dia}}} V_L^{\nu\dagger} = \tilde{\xi}_2 V_L^{\nu\dagger} \,,$$

$$\xi_3 = \frac{1}{\sqrt{\widetilde{\mathbf{m}}_d}} \eta^{-1} U \epsilon^{-1} \sqrt{\mathbf{m}_\nu^{\text{dia}}} V_R^{\nu\dagger} = \tilde{\xi}_3 V_R^{\nu\dagger} \,,$$

$$\epsilon_a = \begin{pmatrix} \varepsilon_1 & 0 & 0 \\ 0 & \varepsilon_2 & 0 \\ 0 & 0 & \varepsilon_3 \end{pmatrix} , \; \epsilon_b = \begin{pmatrix} 0 & 0 & \varepsilon_1 \\ 0 & \varepsilon_2 & 0 \\ \varepsilon_3 & 0 & 0 \end{pmatrix} , \; \epsilon_c = \begin{pmatrix} \varepsilon_1 & 0 & 0 \\ 0 & 0 & \varepsilon_2 \\ 0 & \varepsilon_3 & 0 \end{pmatrix} ,$$

$$\epsilon_d = \begin{pmatrix} 0 & \varepsilon_1 & 0 \\ \varepsilon_2 & 0 & 0 \\ 0 & 0 & \varepsilon_3 \end{pmatrix} , \; \epsilon_e = \begin{pmatrix} 0 & \varepsilon_1 & 0 \\ 0 & 0 & \varepsilon_2 \\ \varepsilon_3 & 0 & 0 \end{pmatrix} , \; \epsilon_f = \begin{pmatrix} 0 & 0 & \varepsilon_1 \\ \varepsilon_2 & 0 & 0 \\ 0 & \varepsilon_3 & 0 \end{pmatrix} .$$

Observables to fit and constrain

Obs.	$\Delta m_{B_d} \cdot 10^{13}$ [GeV]	$\Delta m_{B_s} \cdot 10^{12}$ [GeV]	$S_{J/\Psi K^0}$
Exp. [34]	3.3349 ± 0.0125	11.688 ± 0.003	0.708 ± 0.017
SM [60]	3.496 ± 0.258	11.560 ± 0.063	0.708 ± 0.026
LQ model	3.46	11.50	0.697
Obs.	$S_{J/\Psi\phi}$	$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) \cdot 10^{10}$	$\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) \cdot 10^5$
Exp.	0.036 ± 0.016 [34]	$1.14^{+0.40}_{-0.33}$ [34]	1.3 ± 0.4 [1]
SM	0.0369 ± 0.0017 [60]	0.86 ± 0.042 [6]	0.492 ± 0.03 [6]
LQ model	0.036	1.07	1.06
Obs.	$\mathcal{B}(B \to \tau\nu) \cdot 10^4$	R_D	R_{D^*}
Exp.	1.09 ± 0.24 [34]	0.342 ± 0.026 [80]	0.287 ± 0.012 [80]
SM [60]	0.84 ± 0.07	0.2950 ± 0.0055	0.2451 ± 0.0066
LQ model	0.84	0.323	0.254

Obs.	$\mathcal{B}(\mu \to e\gamma) \cdot 10^{13}$	$\mathcal{B}(\mu \to 3e) \cdot 10^{12}$	$\mathcal{B}(\tau \to e\gamma) \times 10^8$	$\mathcal{B}(\tau \to \mu\gamma) \times 10^8$
EUL	< 4.2 [73]	< 1.0 [74]	< 3.3 [75]	< 4.2 [76]
Obs.	$\mathcal{B}(\tau \to 3e) \cdot 10^8$	$\mathcal{B}(\tau \to 3\mu) \cdot 10^8$	$CR(\mu - e, \mathrm{Au}) \times 10^{13}$	$CR(\mu - e, \mathrm{Ti}) \times 10^{12}$
EUL	< 2.7 [77]	< 2.1 [77]	< 7 [78]	< 4.3 [79]

Best fits

We fit to these observables, using analytical expressions for EFT coefficients, some observables and also FLAVIO (Straub D.M. for meson oscillation and LFV observables).

$$\zeta_{11} \equiv (\xi_4)_{c\mu} \in (-10^{-4},\, 10^{-4})\,,$$
$$\zeta_{21} \equiv (\xi_4)_{t\mu} \in (-10^{-4},\, 10^{-4})\,,$$
$$\zeta_{22} \equiv (\xi_4)_{t\tau} \in (-0.5,\, 0.5)\,.$$

$$\phi_{12}/^\circ = 33.68^{+0.73}_{-0.70},\quad \phi_{23}/^\circ = 43.3^{+1.0}_{-0.8},\quad \phi_{13}/^\circ = 8.56^{+0.11}_{-0.11},\quad \delta_{\rm CP}/^\circ = 212^{+26}_{-41},$$
$$\Delta m^2_{21}/{\rm eV}^2 = (7.49^{+0.19}_{-0.19})\times 10^{-5},\quad \Delta m^2_{3\ell}/{\rm eV}^2 = (2.513^{+0.021}_{-0.019})\times 10^{-3},$$

Direct searches for LQs at LHC bound their masses $\sim > 1.5$ TeV, we fix $m_A = 1.5$ TeV, $m_B = 3$ TeV

(ϵ,η) / $\chi^2_{\rm min}$	$(\epsilon_a,\,\eta_e)$	$(\epsilon_b,\,\eta_e)$	$(\epsilon_c,\,\eta_c)$	(ϵ_d,η_d)	$(\epsilon_e,\,\eta_f)$	$(\epsilon_f,\,\eta_e)$
$\chi^2_{\rm min}$	10.7	12.9	10.8	8.03	9.64	16.3
R_D	0.309	0.307	0.310	0.323	0.316	0.308
$\mathcal{B}(K^+\to\pi^+\nu\bar\nu)\cdot 10^{-10}$	1.05	1.00	1.04	1.07	1.31	0.92
$\mathcal{B}(B^+\to K^+\nu\bar\nu)\cdot 10^{-5}$	1.09	1.29	1.13	1.06	0.97	1.8
$\mathcal{B}(\mu\to e\gamma)\cdot 10^{13}$	1.62	1.97	1.34	2.59	0.66	0.99
$\mathcal{B}(\tau\to e\gamma)\cdot 10^{8}$	1.18	1.52	0.93	0.80	1.25	0.77
$\mathcal{B}(\tau\to \mu\gamma)\cdot 10^{8}$	2.78	0.16	2.49	1.40	0.09	0.25
$CR(\mu-e,{\rm Au})\cdot 10^{13}$	0.05	5.24	6.07	1.04	2.19	1.42

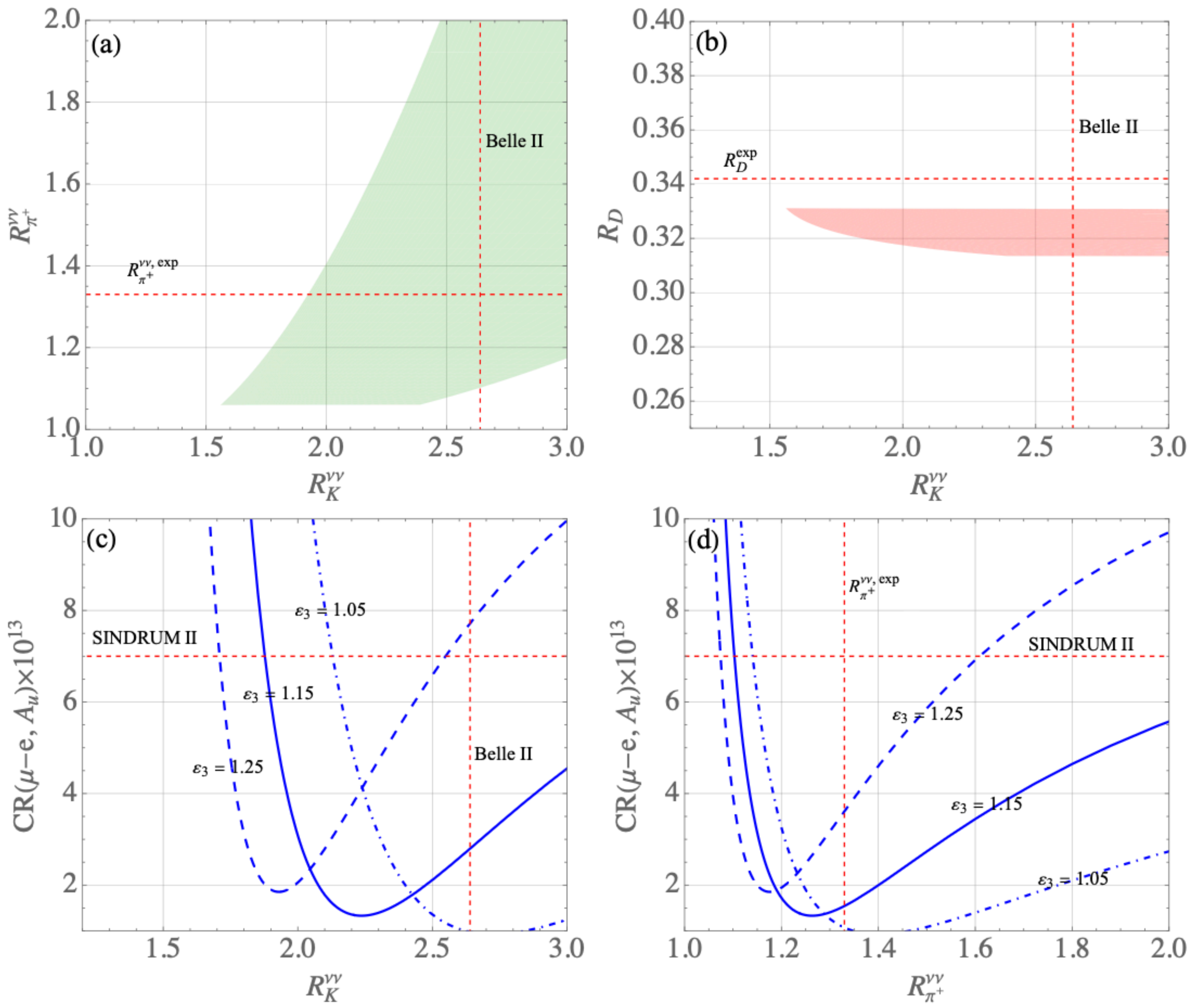


Figure 5. Correlation plots for (a) $R_K^{\nu\nu}$ vs. $R_{\pi^+}^{\nu\nu}$, (b) $R_K^{\nu\nu}$ vs. R_D, (c) $CR(\mu - e, \mathrm{Au})$ vs. $R_K^{\nu\nu}$, and (d) $CR(\mu - e, \mathrm{Au})$ vs. $R_{\pi^+}^{\nu\nu}$. The parameter ranges $\varepsilon_2 \in (0.05, 0.15)$ and $\varepsilon_3 \in (0.8, 1.5)$ are used in plots (a) and (b), while $\varepsilon_2 \in (0.05, 0.15)$ is taken in plots (c) and (d). Vertical and horizontal lines indicate the central values of the current experimental data, except that in plots (c) and (d) the horizontal lines represent the upper limit from SINDRUM II.

So, can new physics be hiding in meson decay anomalies?
Yes.
Rare decays provide an excellent avenue for testing ideas in neutrino mass generation, dark matter, extra scalars, etc.

In the coming years, experiments will improve our knowledge of rare processes. For example KOTO-II @ J-PARC plans to measure $K_L \to \pi^0 \nu\nu$ with a sensitivity of $< 10^{-12}$, more than one order of magnitude below the SM prediction.

Thank you

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